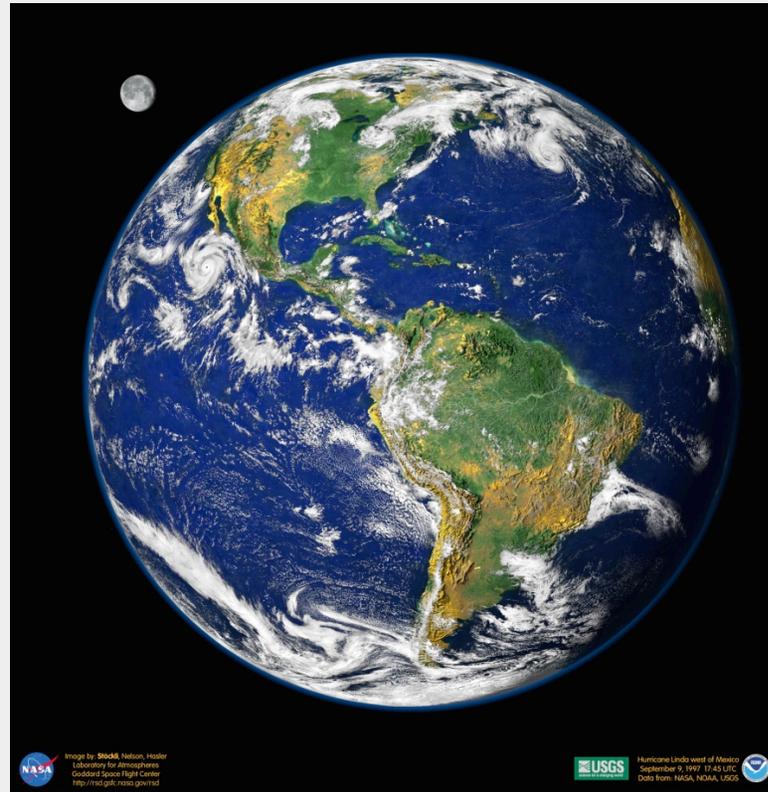


Earth Science and Applications from Space

National Imperatives for the Next Decade and Beyond



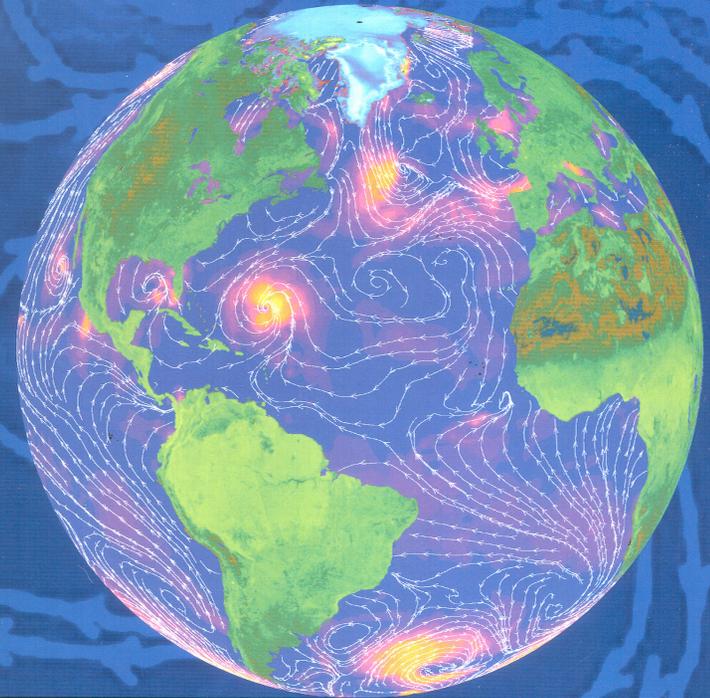
Rick Anthes
NASA ESS@20
22 June 2009

VISION

A healthy, secure, prosperous and sustainable society for all people on Earth

"Understanding the complex, changing planet on which we live, how it supports life, and how human activities affect its ability to do so in the future is one of the greatest intellectual challenges facing humanity. It is also one of the most important for society as it seeks to achieve prosperity and sustainability."

NRC (April 2005)



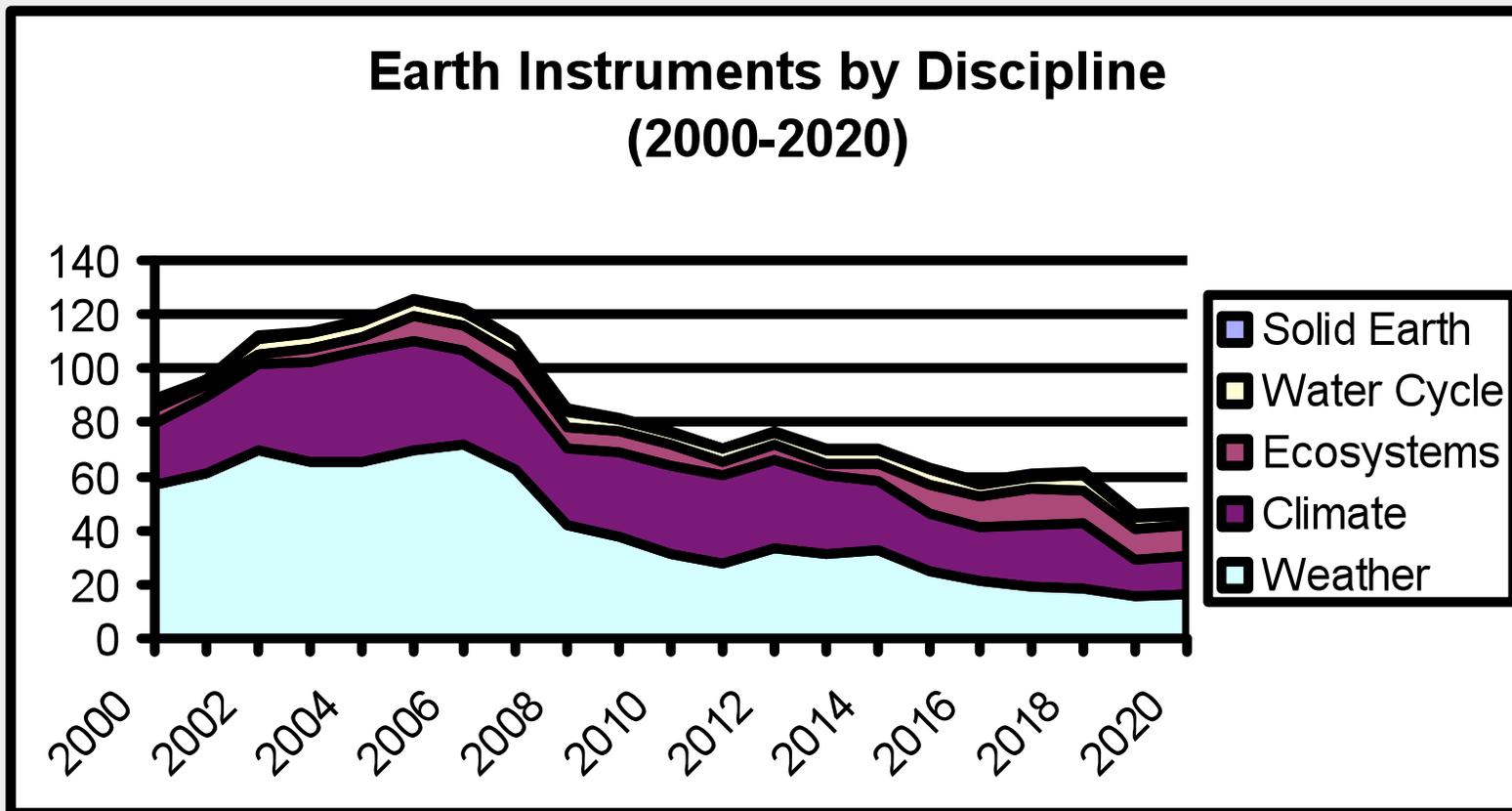
EARTH SCIENCE AND APPLICATIONS FROM SPACE

URGENT NEEDS AND OPPORTUNITIES TO SERVE THE NATION

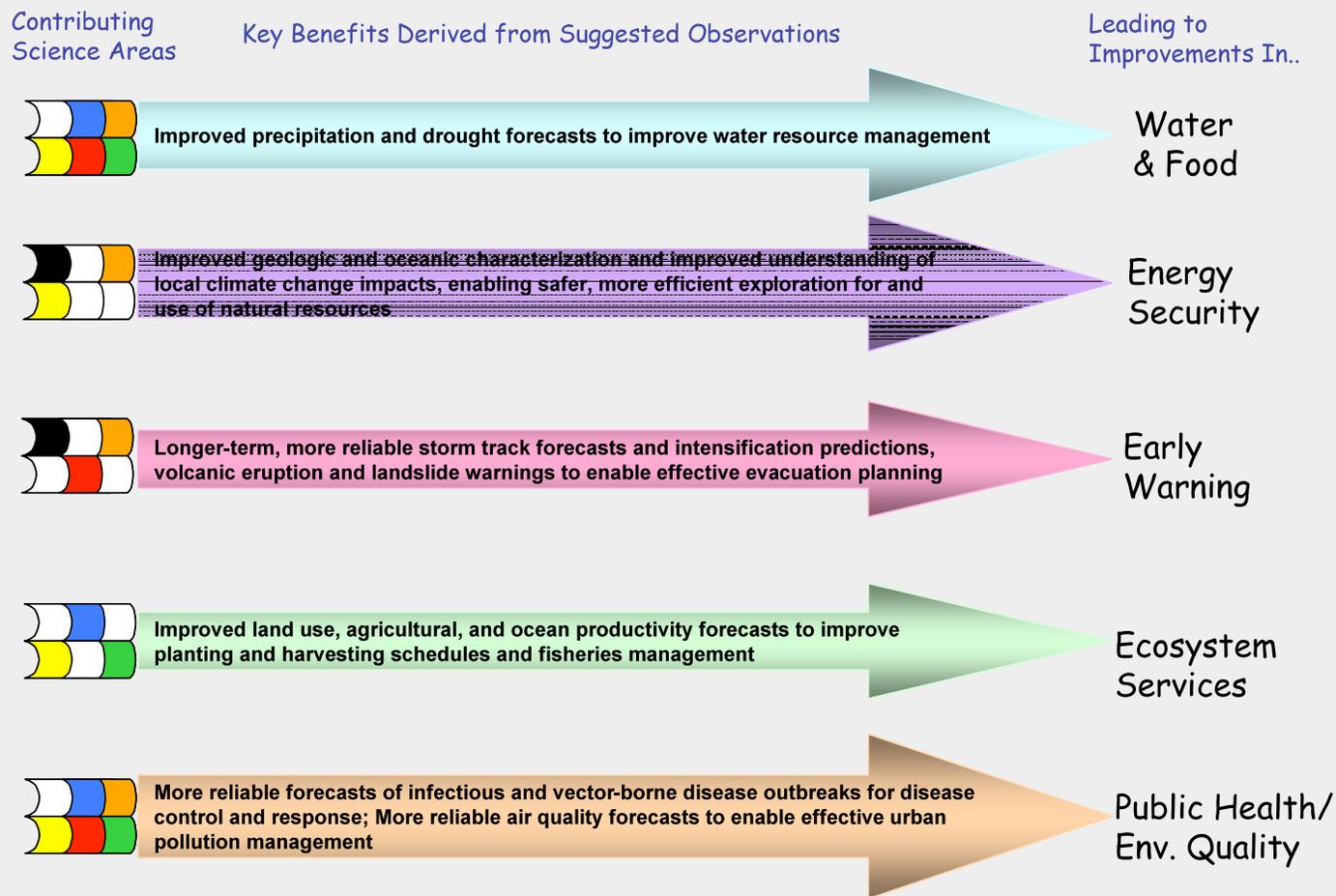
NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

www.nap.edu/catalog/11820.html

“Today, this system of environmental satellites is at risk of collapse”



Need for Interdisciplinary Program



Science Areas

| | | |
|-------------|--------|------------|
| Solid Earth | Water | Weather |
| Climate | Health | Ecosystems |

Weather, climate and Human Health

Dec 1997-Rift Valley Fever in Kenya kills 100,000 stock animals and infects 90,000 people.....

September 2007-satellite observations of ocean temperature in Indian Ocean and model connecting weather conditions in Kenya to mosquitoes and disease provide warning.

When Rift Valley Fever broke out again in December 2007, people were ready---preventing many deaths.



MAIN RECOMMENDATION

(for next decade)

- NOAA and NASA should undertake a set of 17 recommended missions, phased over the next decade

MAIN RECOMMENDATION

(for next decade)

- NOAA research to operations
 - Vector ocean winds
 - GPS radio occultation temperature, water vapor and electron density profiles
 - Measurements of total solar irradiance and Earth radiation should be restored to NPOESS
- NASA
 - 15 missions in small, medium and large categories

17 Missions

(Red = <\$900 M; Green = \$300-\$600 M; Blue = <\$300 M)

| Decadal Survey Mission | Mission Description | Orbit | Instruments | Rough Cost Estimate |
|--|--|----------|----------------------|---------------------|
| Timeframe 2010 - 2013—Missions listed by cost | | | | |
| CLARREO (NOAA portion) | Solar and Earth radiation characteristics for understanding climate forcing | LEO, SSO | Broadband radiometer | \$65 M |
| GPSRO | High accuracy, all-weather temperature, water vapor, and electron density profiles for weather, climate, and space weather | LEO | GPS receiver | \$150 M |
| Timeframe 2013 – 2016 | | | | |
| XOVWM | Sea surface wind vectors for weather and ocean ecosystems | MEO, SSO | Backscatter radar | \$350 M |

Climate Absolute Radiance and Refractivity Observatory

Operational GPS Radio Occultation

Extended Ocean Vector Winds Mission

| Decadal Survey Mission | Mission Description | Orbit | Instruments | Rough Cost Estimate |
|--|---|-----------------|--|---------------------|
| Timeframe 2010 – 2013, Missions listed by cost | | | | |
| CLARREO (NASA portion) | Solar radiation: spectrally resolved forcing and response of the climate system. Each of 3 satellites also carries GPS RO receiver. | LEO, Precessing | Absolute, spectrally-resolved interferometer; GPS receiver | \$200 M |
| SMAP | Soil moisture and freeze/thaw for weather and water cycle processes | LEO, SSO | L-band radar L-band radiometer | \$300 M |
| ICESat-II | Ice sheet height changes for climate change diagnosis | LEO, Non-SSO | Laser altimeter | \$300 M |
| DESDynI | Surface and ice sheet deformation for understanding natural hazards and climate; vegetation structure for ecosystem health | LEO, SSO | L-band InSAR Laser altimeter | \$700 M |
| Timeframe: 2013 – 2016, Missions listed by cost | | | | |
| HypIRI | Land surface composition for agriculture and mineral characterization; vegetation types for ecosystem health | LEO, SSO | Hyperspectral spectrometer | \$300 M |
| ASCENDS | Day/night, all-latitude, all-season CO ₂ column integrals for climate emissions | LEO, SSO | Multifrequency laser | \$400 M |
| SWOT | Ocean, lake, and river water levels for ocean and inland water dynamics | LEO, SSO | Ka-band wide swath radar C-band radar | \$450 M |
| GEO-CAPE | Atmospheric gas columns for air quality forecasts; ocean color for coastal ecosystem health and climate emissions | GEO | High and low spatial resolution hyperspectral imagers | \$550 M |
| ACE | Aerosol and cloud profiles for climate and water cycle; ocean color for open ocean biogeochemistry | LEO, SSO | Backscatter lidar Multiangle polarimeter Doppler radar | \$800 M |

Climate Absolute Radiance
And Refractivity Observatory

Soil Moisture
Active-Passive

Ice, Cloud, and land
Elevation SATellite II

Deformation, Ecosystem Structure
and Dynamics of Ice

Hyperspectral Infrared Imager

Active Sensing of CO₂ Emissions
Over Nights, Days and Seasons

Surface Water and
Ocean Topography

Geostationary Coastal
And Air Pollution Events

9
Aerosol-Cloud-Ecosystems

| Timeframe: 2016 -2020, Missions listed by cost | | | | |
|--|---|----------|--|---------|
| LIST | Very high resolution land surface topography for landslide hazards and water runoff | LEO, SSO | Laser altimeter | \$300 M |
| PATH | High frequency, all-weather temperature and humidity soundings for weather forecasting and SST ^a | GEO | MW array spectrometer | \$450 M |
| GRACE-II | High temporal resolution gravity fields for tracking large-scale water movement | LEO, SSO | Microwave or laser ranging system | \$450 M |
| SCLP | Snow accumulation for fresh water availability | LEO, SSO | Ku and X-band radars K and Ka-band radiometers | \$500 M |
| GACM | Ozone and related gases for intercontinental air quality and stratospheric ozone layer prediction | LEO, SSO | UV spectrometer IR spectrometer Microwave limb sounder | \$600 M |
| 3D-Winds (Demo) | Tropospheric winds for weather forecasting and pollution transport | LEO, SSO | Doppler lidar | \$650 M |

Lidar Surface Topography

Precipitation and All Weather Temperature And Humidity

Gravity Recovery and Climate Exp II

Snow and Cold Land Processes

Global Atmospheric Composition Mission

3D Tropospheric Winds

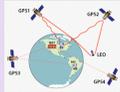
[1] Cloud-independent, high temporal resolution, lower accuracy SST to complement, not replace, global operational high-accuracy SST measurement



Changes in carbon storage in vegetation

DESDynI

Launch 2010-2013



Pressure/temperature/water vapor profiles

GPSRO

Launch 2010-2013



Estimate of flux of low-salinity ice out of Arctic basin

ICESat-II

Launch 2010-2013



Aerosol and cloud types and properties

ACE

Launch 2013-2016



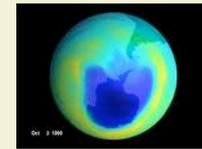
CO₂ measurements: Day/night, all seasons, all latitudes



Connection between climate and CO₂ exchange

ASCENDS

Launch 2013-2016



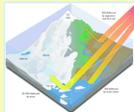
Vertical profile of ozone and key ozone precursors

GACM

Launch 2016-2020



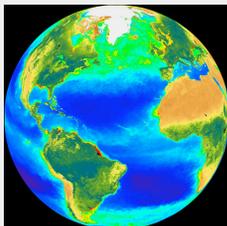
Absolute spectrally resolved IR radiance



Incident solar and spectrally resolved reflected irradiance

CLARREO

Launch 2010-2013



Societal Challenge: Climate Prediction

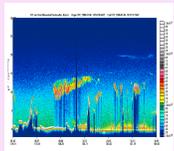
Robust estimates of primary climate forcings for improved climate forecasts, including local predictions of the effects of climate change



Linkage between terrestrial water, energy, and carbon cycle

SMAP

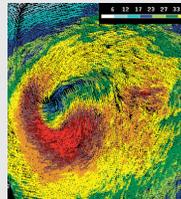
Launch 2010-2013



Cloud and aerosol height

ACE

Launch 2013-2016



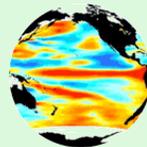
High resolution ocean vector winds

XOVWM

Launch 2013-2016



Temperature and humidity profiles



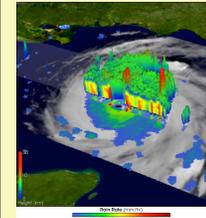
Sea surface temperature

PATH

Launch 2016-2020



Three dimensional tropospheric wind profiles



Hurricane wind fields

3D-Winds

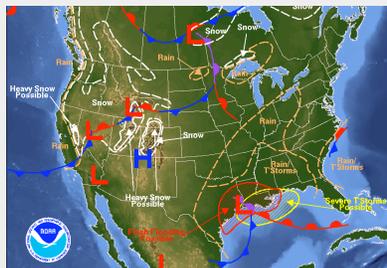
Launch 2020+



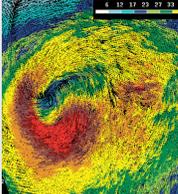
Pressure/temperature/water vapor profiles

GPSRO

Launch 2010-2013

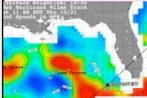


Societal Challenge: Improved Weather Prediction
Longer-term, more reliable weather forecasts



High resolution ocean vector winds

XOVWM
Launch 2013-2016

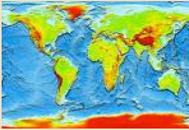


Sea level measurements extended into coastal zones



Ocean eddies and currents

SWOT
Launch 2013-2016



Global high resolution topography



Detection of active faults

LIST
Launch 2016-2020



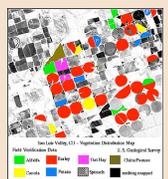
Snow pack accumulation and Snowmelt extent

SCLP
Launch 2016-2020



Changes in Earth's surface and movement of magma

DESDynI
Launch 2010-2013



Nutrients and water status of vegetation, soil type and health

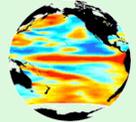


Processes indicating volcanic eruption

HyspIRI
Launch 2013-2016



Temperature and humidity profiles

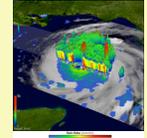


Sea surface temperature

PATH
Launch 2016-2020

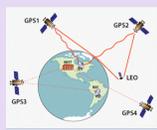


Three dimensional tropospheric wind profiles



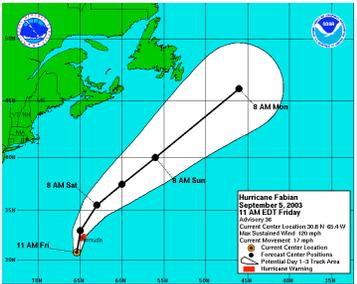
Hurricane wind fields

3D-Winds
Launch 2020+

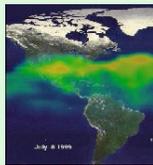


Pressure/temperature/water vapor profiles

GPSRO
Launch 2010-2013



Societal Challenge: Extreme Event Warnings
Longer-term, more reliable storm track forecasts and intensification predictions, volcanic eruption and landslide warnings to enable effective evacuation planning.



Identification of human vs. natural sources for aerosols and ozone precursors



Observation of air pollution transport in North, Central, and South America

GEO-CAPE
Launch 2013-2016



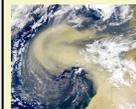
Temperature and humidity profiles

PATH
Launch 2016-2020



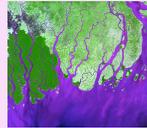
Three dimensional tropospheric wind profiles

3D-Winds
Launch 2020+



Global aerosol and air pollution transportation and processes

GACM
Launch 2016-2020



River discharge estimates

SWOT
Launch 2013-2016



Pressure/temperature/water vapor profiles

GPSRO
Launch 2010-2013



Societal Challenge: Human Health

More reliable forecasts of infectious and vector-borne disease outbreaks for disease control and response



Changes in
Earth's surface

DESDynI
Launch 2010-2013

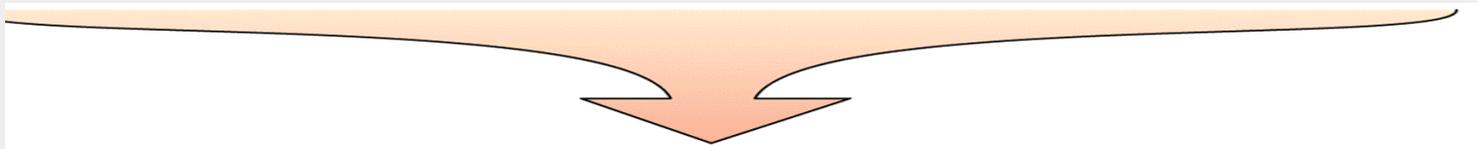


Global
high
resolution
topography



Detection
of active
faults

LIST
Launch 2016-2020



Societal Challenge: Earthquake Early Warning
Identify active faults and predict likelihood of earthquakes to enable effective investment in structural improvements, inform land use decisions, and provide early warning of impending earthquakes



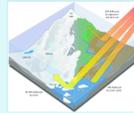
Ice sheet deformation and dynamics

DESDynI

Launch 2010-2013



Absolute spectrally resolved IR radiance
Incident solar and spectrally resolved reflected irradiance



CLARREO

Launch 2010-2013



Ice sheet mass, volume, and distribution

GRACE-II

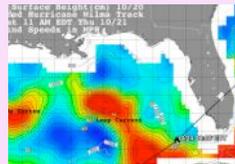
Launch 2016-2020



Ice sheet thickness and volume

ICESat-II

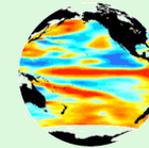
Launch 2010-2013



Sea level measurements extended into coastal zones

SWOT

Launch 2013-2016



Sea surface temperature

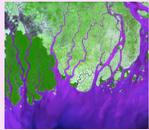
PATH

Launch 2016-2020

Societal Challenge: Sea Level Rise

Climate predictions based on better understanding of ocean temperature and ice sheet volume changes and feedback to enable effective coastal community planning

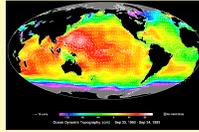




River discharge estimates

SWOT

Launch 2013-2016



Changes in aquifers and deep ocean currents

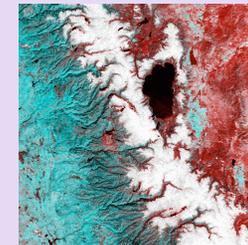
GRACE-II

Launch 2016-2020



Snow pack accumulation and Snowmelt extent

Snow water equivalent, snow depth, and snow wetness



Dynamics of water storage in seasonal snow packs

SCLP

Launch 2016-2020



Pressure/temperature/water vapor profiles

GPSRO

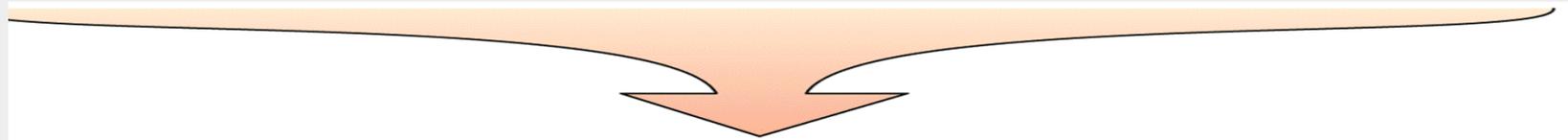
Launch 2010-2013



Temperature and humidity profiles

PATH

Launch 2016-2020



Societal Challenge: Freshwater Availability
Improved precipitation and drought forecasts to improve water resource management



Nutrients and water status of vegetation, soil type and health

HyspIRI

Launch 2013-2016



Height and structure of forests

DESDynI

Launch 2010-2013



Soil freeze/thaw state



Soil moisture effect on vegetation

SMAP

Launch 2010-2013



Ocean eddies and currents

SWOT

Launch 2013-2016



Dynamics of coastal ecosystems, river plumes, tidal fronts

GEO-CAPE

Launch 2013-2016



Improved estimates of coastal upwelling and nutrient availability

XOVWM

Launch 2013-2016



CO₂ measurements: Day/night, all seasons, all latitudes



Inventory of global CO₂ sources and sinks

ASCENDS

Launch 2013-2016



Organic material in surface ocean layers

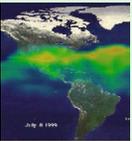
ACE

Launch 2013-2016



Societal Challenge: Ecosystem Services

Improved land use, agricultural, and ocean productivity forecasts to improve planting and harvesting schedules and fisheries management

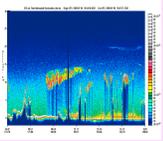


Identification of human vs. natural sources for aerosols and ozone precursors



Observation of air pollution transport in North, Central, and South America

GEO-CAPE
Launch 2013-2016



Cloud and aerosol height



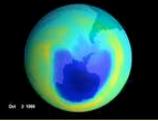
Aerosol and cloud types and properties

ACE
Launch 2013-2016

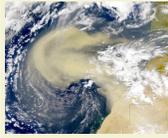


Three dimensional tropospheric wind profiles

3D-Winds
Launch 2020+

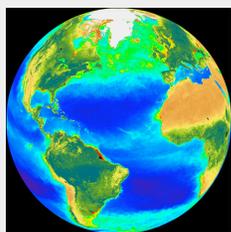
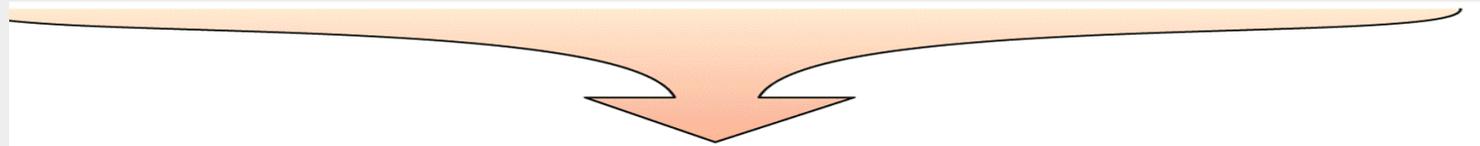


Vertical profile of ozone and key ozone precursors

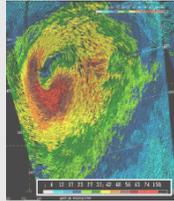


Global aerosol and air pollution transportation and processes

GACM
Launch 2016-2020



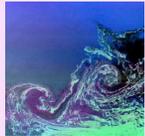
Societal Challenge: Air Quality
More reliable air quality forecasts to enable effective urban pollution management.



High resolution
ocean vector
winds

XOVWM

Launch 2013-2016



Ocean
eddies and
currents

SWOT

Launch 2013-2016



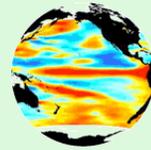
Pressure/
temperature/
water vapor
profiles

GPSRO

Launch 2010-2013



Temperature
and humidity
profiles



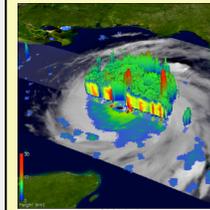
Sea surface
temperature

PATH

Launch 2016-2020



Three
dimensional
tropospheric
wind profiles



Hurricane
wind fields

3D-Winds

Launch 2020+



Societal Challenge: Improved Extreme Storm Warnings

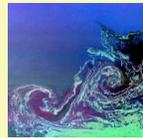
Longer-term, more reliable storm track forecasts and intensification predictions to enable effective evacuation planning



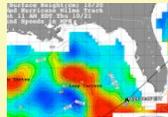
Linkage between terrestrial water, energy, and carbon cycle

SMAP

Launch 2010-2013



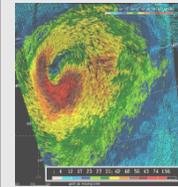
Ocean eddies and currents



Sea level measurements extended into coastal zones

SWOT

Launch 2013-2016



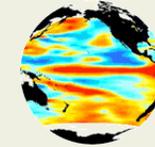
High resolution ocean vector winds

XOVWM

Launch 2013-2016



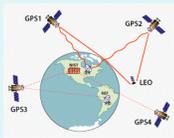
Temperature and humidity profiles



Sea surface temperature

PATH

Launch 2016-2020



Pressure/temperature/water vapor profiles

GPSRO

Launch 2010-2013



Spectra to identify locations of natural resources

HyspIRI

Launch 2013-2016



CO₂ measurements: Day/night, all seasons, all latitudes



Inventory of global CO₂ sources and sinks

ASCENDS

Launch 2013-2016



Three dimensional tropospheric wind profiles

3D-Winds

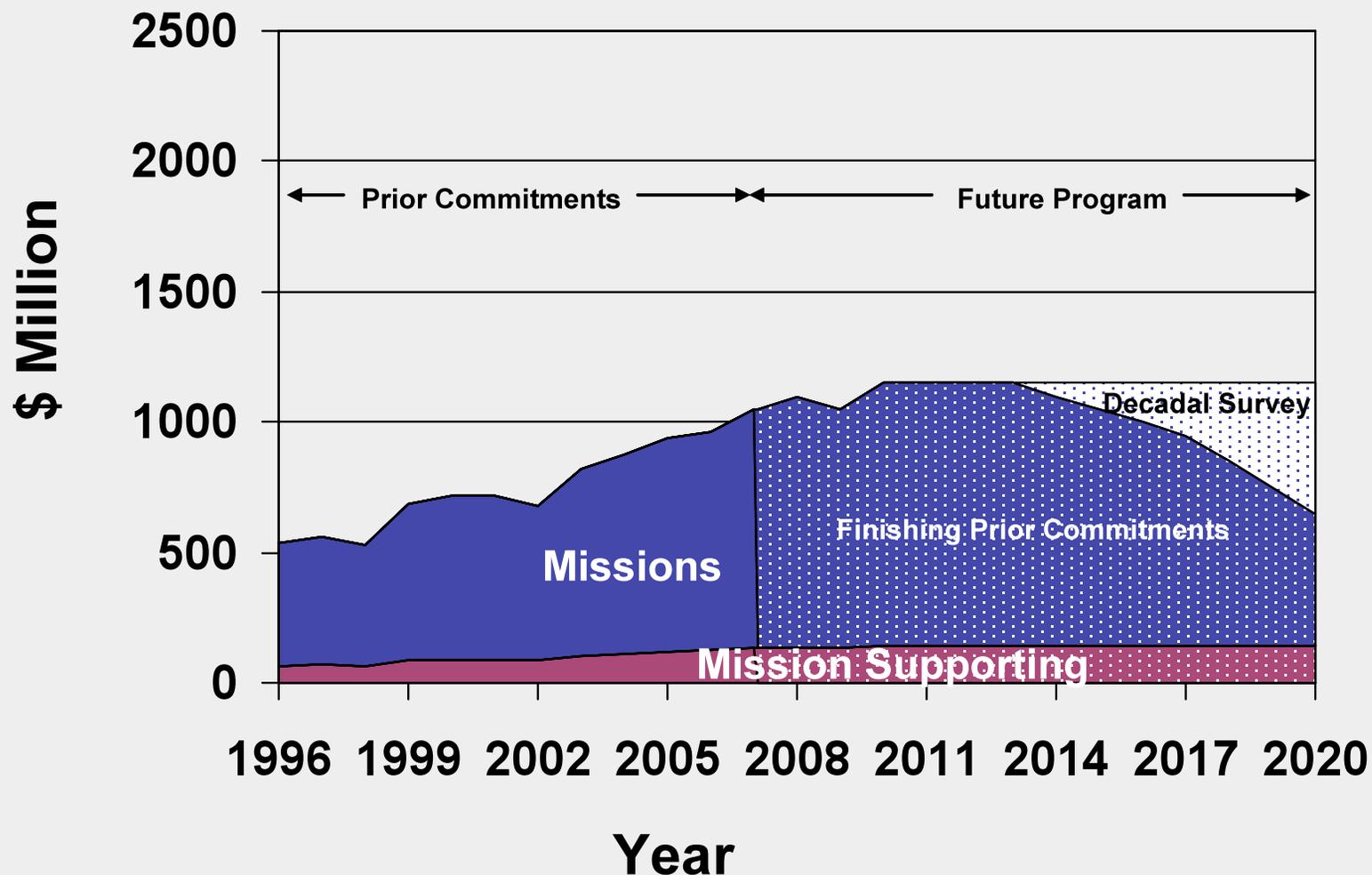
Launch 2020+



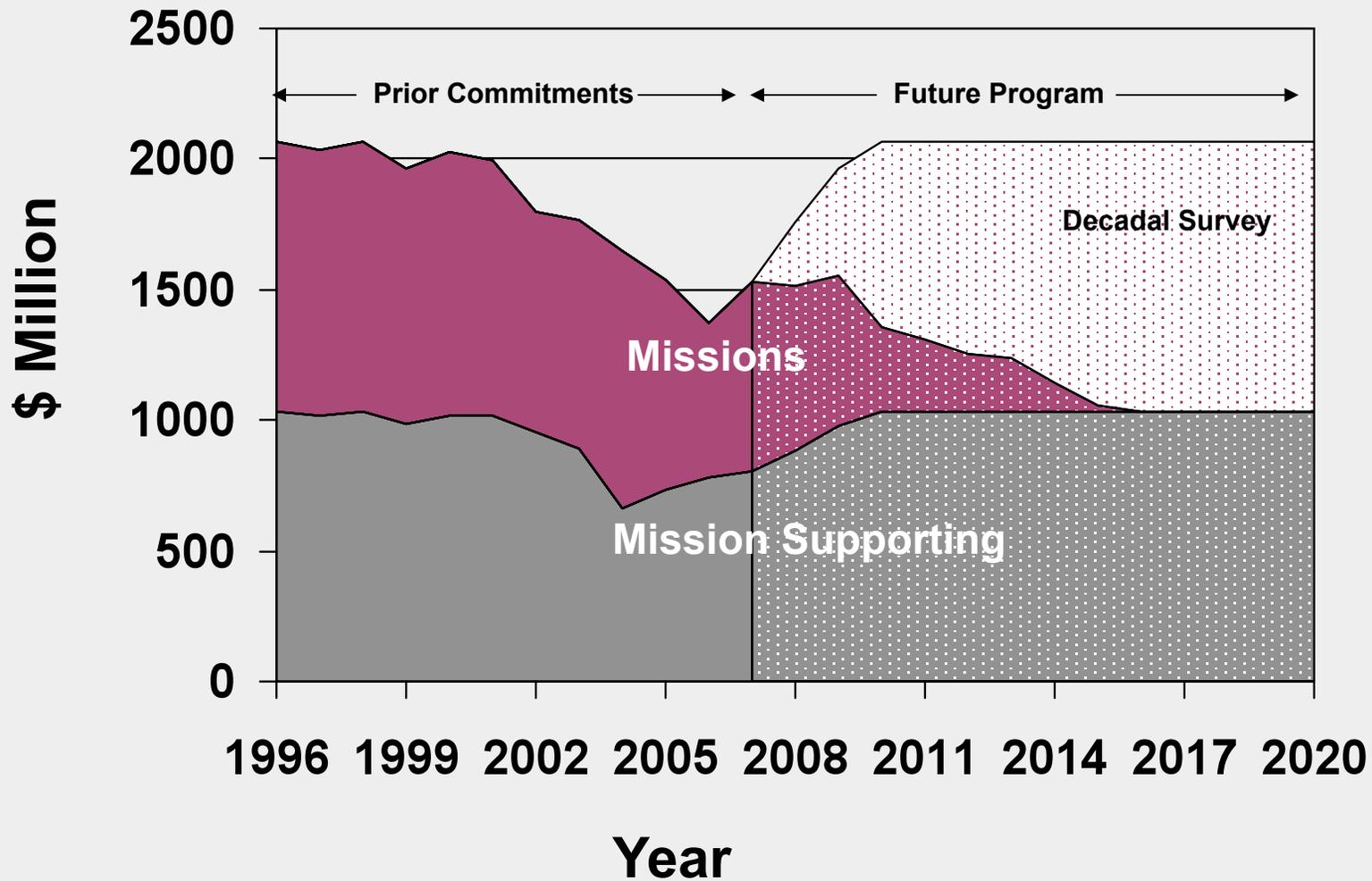
Societal Challenge: Energy Security

Improved energy security through more effective oil and gas exploration, safer extraction through improved marine forecasts, optimized placement of wind farms through measurement of global winds, better energy conservation through improved heating/cooling forecasts, and support of carbon trading and energy policy.

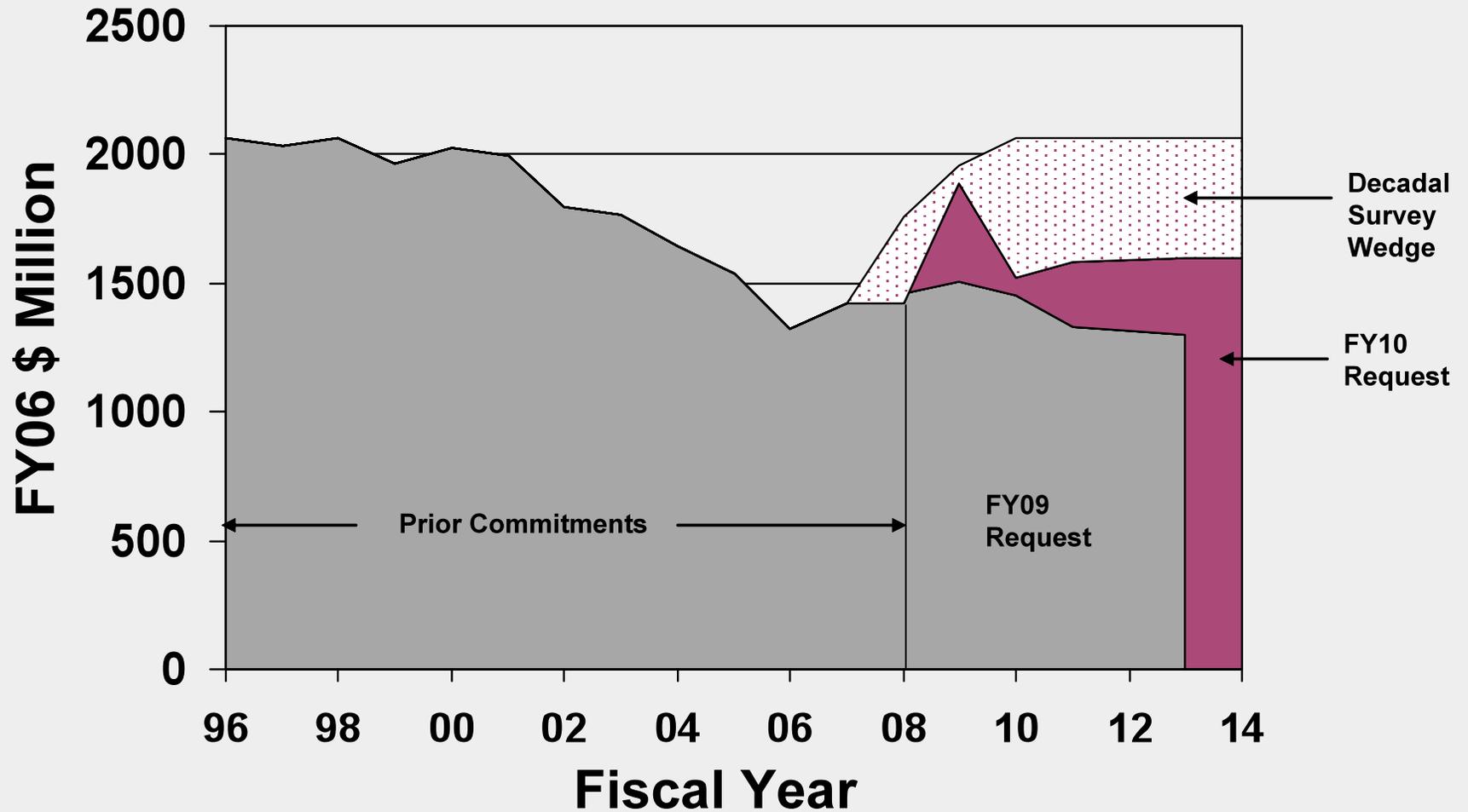
Implementing the Decadal Survey-NOAA Budget



NASA Earth Science Program: Rapid Return to 2000 Funding Levels



Comparison between President's **FY10** NASA request and NRC recommendation



Thank you!

